Factors Influencing Occurrence, Scale, Mobility, Runout, and Morphology of Mass Movements on the Continental Slope: Final Report (ending in fiscal year 99)

Jacques Locat
Department of Geology and Geological Engineering, Laval University
Sainte-Foy, Québec, CANADA G1K 7P4
phone: (418) 656 2179, fax: (418) 656-7339, email: locat@ggl.ulaval.ca
Award Number: N00014-98-1-0073
Htpp://www.ggl.ulaval.ca

LONG-TERM GOALS

Achieve an improved understanding of the relationships between sedimentation, environment, and the morphology of continental slopes. This goal will be accomplished primarily through investigations within the northern California (Eel River) study area and incorporation of data from around the World. An underlying assumption of our work is that the occurrence and morphology of mass movement features on the continental slope depend upon a combination of characteristics, each of which varies over the region in a consistent manner. The various components of this project are part of a concerted effort between the geotechnical groups at the USGS and Laval University. Their activities are very much interwoven but, for administrative reasons, their respective budgets are identified separately as are the annual reports.

OBJECTIVES

Identify factors that can be mapped regionally and that determine where and how slope failures occur; derive a basis for producing regional maps that indicate relative landslide susceptibility. Model shear strength development with depth and incorporate this model into continental slope stability, post-failure behavior, and bedform processes. Observe and model pore pressure development in continental slopes. Analyze the relationship between seismic intensity, sediment instability and slope processes.

APPROACH

Our research focuses on the factors that lead to variations in the sedimentological and environmental conditions determining slope failure. We develop improved correlations between engineering classifications and strength factors. We relate compressibility, physico-chemical properties and strength to sediment microstructure, observed using SEM techniques. We simulate sediment accumulation in specially designed large cells. We measure sediment rheological properties in a viscometer. Geotechnical properties are related to sediment density state, obtained from detailed logs of downcore variability of sediment density and sound velocity. Using available bathymetry, we construct slope maps. Seismic shaking variations are evaluated probabilistically by seismologists. *In situ* pore pressures are determined by means of the Excalibur probe (AGC-Atlantic). These pressures can be generated if the sedimentation rate is particularly rapid, if there is charging by bubble-phase gas, or if earthquake shaking disrupts the sediment fabric and causes it to collapse with a resulting increase in the pressure of interstitial fluids. Driving stresses are balanced against strength variations in a geographic Information System (GIS) to obtain a regional estimate of relative slope stability.

Key individuals, at Laval: Jacques Locat, Jean-Marie Konrad, Éric Boulanger, and Priscilla Desgagnés: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation.; at the USGS: Homa Lee, Kevin Orzech, Dianne Minasian, and Pete Dartnell: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS.

WORK COMPLETED

During FY 99, our research involved ~~two~~ the two main areas of STRATAFORM: Eel river margin and New Jersey Margin. For the Eel River Margin, we continued the laboratory testing and analysis of tests carried out on various cores obtained from the 1998 Wecoma oceanographic cruise to the Eel Margin (9807A, July 15-24, 1998). Further tests conducted at Laval included oedometer tests, SEDCON tests, simple shear tests, Atterberg's limits, grain size, mineralogy, microstructure and rheology. É. Boulanger completed the initial work on seismic strengthening of Eel river margin sediments by carrying OUT a total of 25 cyclic shear tests on reconstituted samples (Boulanger 1999). Most of these data are entered into a GIS to evaluate regional variations in sediment properties and environmental loads. Algorithms convert these data into estimates of slope stability. During FY 99, our field work was concentrated on the East Coast, within the New Jersey Margin area in conjunction with the Marion Dufresne ocaenographic cruise. At that occasion, a group of three scientists from Laval (P. Desgagnés, P. Côté, and M.-C. Héroux) joined the STRATAFORM research team led by C. Alexander. The main purpose of the Marion Dufresne cruise was to take Calypso cores (20 to 50m long) in a landslide area within the Hudson Apron. A total of 3 long cores were collected (MD992-211, 212, and 213), of which one is kept at Laval and is to be shared with THE USGS group for various geotechnical tests. All cores were logged, onboard the ship, at 1-cm resolution for density, sound velocity, and magnetic susceptibility. In addition, core MD992-213 was completely logged with a CATSCAN at a resolution of 1cm. P. Desgagnés participated IN laboratory testing at Lamont Doherty Laboratories on core MD992-211 mostly to carry out strength tests (Desgagnés, 1999). In addition, many members of the STRATAFORM group joined OUR efforts in illustrating the use of multibeam surveys for the study of submarine landslide features in many parts of the World. In carrying out the above mentioned work, we participated, in addition to the annual meeting in San Francisco, in a Slope Group meeting in Boulder Colorado.

RESULTS

Classic slope failure features on the Eel Margin are rare even though our methodology shows a high vulnerability to slope failure during seismic loading, indicating either that mass wasting on the Eel Margin takes unexpected forms or that mass wasting is less significant than would be expected. Studies of shear strength development show a bi-linear function, resulting from bioturbation. Rheological studies of Eel Margin sediment show a highly thixotropic material, represented by a pseudo-Bingham model. Analyses of reconstituted specimens of the Eel river Sediments reveals that, under drained cyclic loading, the undrained shear strength increases significantly. Although these conclusions are derived from tests on re-constituted sediments, we can now formulate a working hypothesis: seismic strengthening is a significant mechanism for explaining the paucity of shallow landslide features in the Eel River Margin area.

IMPACT/APPLICATION

Relationships developed in this project show the importance of sediment liquidity index and seabed density profiles in representing the behavior of marine sediment. These values can be used to predict regional slope stability and the rheological behavior of debris flows. General strength-density RELATIONSHIPS can be used for modeling sediment accumulation and stability.

TRANSITIONS

Geoacoustic properties are being used by mappers and acousticians to identify lithologies acoustically. Rheological properties are being used by modelers to represent debris flows. Landslide generation models are being used by landscape evolution modelers. Offshore research groups interested in margin (January 1999 Paris Workshop) and in oil and energy development (September 1999 London Workshop) were used as A platform to present our knowledge on submarine slope stability and hazard acquired as part of STRATAFORM . Along these lines, a meeting was held at the University of Minnesota with G. Parker to interface our activities and research interest on debris flows.

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin that uses techniques produced by STRATAFORM. Locat is investigating the behavior of a newly formed sediment layer acting as a natural cap over contaminated sediment in Canada. The development of this project benefited from approaches developed within STRATAFORM.

REFERENCES

Boulanger, É., Locat, J., Desgagnés, P. Martin, F., and Lee, H., 1998. Geotechnical testing of Eel River sediments collected as part of the R/V Wecoma Cruise # W9807A (July 14 – 25th 1998). Department of Geology and Geological Engineering, Laval University, Québec, CANADA, GREGI Report 98-02, 45 p.

Boulanger, É., 1999. Comportement cyclique des sédiments de la marge continentale de la rivière Eel: une explication possible pour le peu de glissements sous-marins superficiels dans cette région. M. Sc. Thesis, Department of Geology and Geological Engineering, Laval University, Sainte-Foy, Qc, Canada, 145 p.

Desgagnés, P., 1999. STRATAFORM PROJECT: Preliminary report on the geotechnical aspects of the Marion dufresne Cruise 99-2, off New Jersey, June 1999. Report GREGI MD992-06, 5 p. + figures.

PUBLICATIONS

Boulanger, É., Konrad, J.-M., Locat, J., and Lee, H.J., 1998. Cyclic behaviour of Eel River sediments: a possible explanation for the paucity of submarine landslide features. AGU Fall meeting, San Francisco, Abstracts.

Lee, H.J., Dartnell, P., Israel, K., Wong, F., and Locat, J., 1998. Evaluating shallow-seated submarine slope stability: comparison between the Eel margin and the Los Angeles margin, California. In: STRATCON '98: "STRATA AND SEQUENCES ON SHELVES AND SLOPES", SEPM-IAS Research Conference, Sicily, September 14-19th 1998, Abstract.

Lee, H.J., , Dartnell, P., Minasian, D., Wong, F., Israel, K., and Locat, J., 1998. Shallow-Seated Slope Stability Contrasts: Eureka, CA vs. Santa Monica Bay, CA. AGU Fall meeting, San Francisco, Abstracts.

Lee, H.A., Locat, J., Dartnell, P., Israel, K., and Wong, F., 1999. Regional variability of slope stability: application to the Eel Margin, California. Marine Geology, 154: 305-322.

Lee, H.J., Locat, J., Dartnell, P., Minasian, D., and Wong, F., 2000. A GIS-based regional analysis of the potential for shallow-seated submarine slope failure. Accepted for publication, 8th International Symposium on Landslides, Cardiff, England, In press.

Locat, J., 1999. Geotechnical aspects of submarine landslides along ocean margins. Invited Article, Marine and Petroleum Geology, in press.

Locat, J., Lee, H.J., Boulanger, É., and Maurice, F., 1998. Rapid sedimentation, the role of bioturbation and shear strength development: comparison between the Eel River Margin (California) and Saguenay Fjord (Québec) sediments. . In: STRATCON '98: "STRATA AND SEQUENCES ON SHELVES AND SLOPES", SEPM-IAS Research Conference, Sicily, September 14-19th 1998, Abstract.

Locat, J. Lee. H.J., Kayen, R., Israel, K., Savoie, M.-C., and BOULANGER, É., 1999. Shear strength development with burrial in recent Eel River Margin slope sediments. Soumis à la revue: Marine Geotechnology and Resources.

Locat, J., Mayer, L., Gardner, J., Lee, H., Kammerer, E., and Doucet, N., 1999. The use of multibeam surveys for submarine landslide investigations. Invited Article. International Symposium on: Slope Stability Engineering: Geotechnical and Geoenvironmental Aspects, Shikoku, Japan, 8 p., in press.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT DATE	3. DATES COVERED *(From - To)*
99.11.15	Final	Nov. 1st 1998 - Oct. 30th, 199

4. TITLE AND SUBTITLE
FACTORS INFLUENCING OCCURENCE, SCALE, MOBILITY, AND MORPHOLOGY OF MASS MOVEMENTS ON THE CONTINENTAL SLOPE

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
-

6. AUTHOR(S)
Jacques LOCAT

5d. PROJECT NUMBER
-

5e. TASK NUMBER
-

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Laval University
Faculty of Sciences and Engineering
Sainte-Foy (Québec)., Canada G1K7P4

8. PERFORMING ORGANIZATION REPORT NUMBER
-

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
OFFICE OF NAVAL RESEARCH
c/o Joseph H. Kravitz
Ballston Center Tower One
800 North Quiney Street
Arlington, VA 2217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
-

12. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public releas e

13. SUPPLEMENTARY NOTES
-

14. ABSTRACT

Density index properties can be used with shear strength to evaluate relative regional stability (landslides . A bi-linear model for the rheology of muds. Bioturbation and early strength development. Seismic strengthening for impact of earthquakes on strength in silty sediments.

15. SUBJECT TERMS
Liquidity index, submarine landslides, mobility, flow, geotechnical properties, microstructure

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPONE NUMBER *(Include area code)*